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Pavement Material and Technology Elements in Green Highway Rating Systems-A Conspectus

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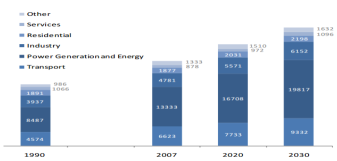
Graphical abstract



Abstract

Since the effect of global warming and climate changes are becoming serious issues nowadays, most countries are trying to develop their own green highway rating system in order to implement the sustainable practices on their highway.Several studies have discussed the issues relating to the sustainable rating system, but no major study has been conducted to examine the green highway rating system in depth.Material and pavement technology are two most important parameters in the green highway rating systems and need to be addressed more critically. This study presents an extensive review to identify and establish the material and pavement technology elements that are most appropriate to be considered in developing the green highway rating systems.The relevant literatures have been reviewed to assist in identifying the elements of material and pavement technology. These elements in existing green highway rating systems are tabulated and ranked to show the importance level of each element. Understanding the comparison between these elements in existing green highway rating systems would help in identifying and overcoming the scarcity of the elements. Subsequently, the complete highway rating system can be developed as a performance measure or baseline reference that suit different environment and weather. The result shows that themost appropriate elements in material and pavement technology in highway development are recycled materials and regional materials.These elements could optimize the sustainable designs, encourage the usage of recycled materials, and minimize the transportation that help in reducing pollution and energy consumption.

Keywords: Sustainability; highway rating system; material and pavement technology

■1.0 INTRODUCTION

A growing global demand has been reported in passenger and freight transportation activities by United Nations Environment Program [1]. Unfortunately, such increasing in transportation demand leads to consuming more than half of global liquid fossil fuels and spending nearly a quarter of global energy-related carbon dioxide (CO_2) which is predicted to be doubled by 2050 [2]. Figure 1 highlights the huge energy consumption and the trend of change in transportation and other different sectors between 2007 and 2030.

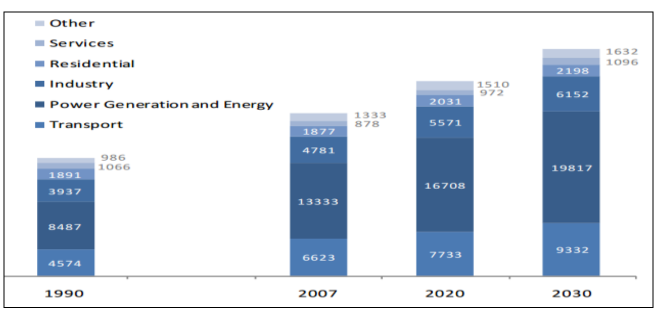


Figure 1 Projected world energy-related CO_2 emissions (Mt)[2]

Sustainability is a word that always arising in the civil engineering industry over the last decade that has the greatest potential to affect change [3]. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs [4]. In order to achieve the sustainability, three major aspects need to be focused which are economic development, environmental, and social. The financial and economic needs of current and future generations need to be answered and should be met. Then, ensuring a clean environment for present and future generations also need to be considered and all natural resources can be conserved. For social aspect, the quality of life for all human can be improved and the equity between society, groups, and generations can be promoted [5].

Transportation is a large contributor to the environmental impacts, especially harmful CO_2 emissions that would increase global warming. It is considered that transportation consumes 22 percent of the global energy, burns about 25 percent of fossil fuel, and release 30 percent of air pollution and greenhouse gasses [5]. These factors contribute to the growing concerns of depletion of natural and non-renewable resources, global climate changing, disruption of ecosystems, and toxic pollution [5]. Since rising incomes are associated with higher levels of car ownership and usage [6] and greater trip rates and distances [7], transport activity and resulting CO_2 emissions could increase significantly along with economic growth and consumer clout.

Therefore, sustainable practices should be implemented to reduce these impacts on the environment and achieve the green highway as well. There are programs and tools available that promote sustainability, such as Leadership in Energy and Environmental Design (LEED) rating system developed by the United States Green Building Council (USGBC). However, LEED is a rating system for sustainable building practices and operation only. The rating systems have been used in building constructions at first and has been gradually applied in infrastructure works and transportation sector in particular [8].

Research has been conducted over the past few years to determine the sustainable transportation practices. Martina Soderlund at the University of Washington did the first successful efforts on sustainable transportation practices and developed a rating system. The framework of the rating system incorporated many aspects from LEED, such as using credits to award sustainable choices and practices, different level of certification, and the general layout of each credit [9]. The works were further developed by using the rating system, which is now called Greenroads. Another rating system for transportation Leadership in Transportation and Environmental Sustainability (GreenLITES), was developed by the New York States Department of Transportation (NYSDOT) and began reviewing projects on September 25, 2008 for certification. Green LITES was derived from the ideas and concepts behind Greenroads, but it is self-certifying and only used for New York State transportation projects [10].

In addition, a document entitled Illinois Livable and Sustainable Transportation (I-LAST) Rating System and Guide was developed by the Joint Sustainability Group of the Illinois Department of Transportation (IDOT), the American Council of Engineering Companies-Illinois (ACEC-Illinois), and the Illinois Road and Transportation Builders Association (IRTBA). GreenPave was designed as a simple point based rating system to assess the greenness of pavements. It was primarily based on the Greenroads and GreenLITES rating systems and developed for the Ontario region. Besides, this rating system focuses specifically on the pavement components rather than the whole roadway.

Envision is a rating system for sustainable infrastructures that involve water storage and treatment, energy generation, landscaping, transportation, and information system. This system encourages the application of life cycle analysis throughout planning, design, construction, and operation stages in order to improve the green performance [11]. There are 60 credits distributed in five categories and Envision provides four certifications for any projects implement the criteria include an Acknowledgement of Merit, Silver Award, Gold Award, and Platinum Award [11].

Another green highway tools named Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) was developed by the Federal Highway Administration (FHWA) and CH2M Hill in 2012 [12]. It was designed specifically for planning, project development, operation and maintenance stages with total 51 or 60 criteria depending on either basic or extended scorecard is used [13]. Besides, this system also provides a certification level based on the scores obtain for each criterion in any project which are Bronze, Silver, Gold, and Platinum.

This paper focuses on the six above mentioned highway rating systems, namely; Greenroads, I-LAST, GreenLITES, GreenPave, Envision, and INVEST. According to these rating systems, material and pavement technology is one of the categories that need to be addressed more critically because any highway project involves the consumption of resources and implements several techniques in their development plans. However, the issues that need to be raised here are how green the highway is constructed, how much natural resources can be conserved, what green techniques can be implemented to reduce energy consumption in highway projects, and what are the most appropriate element that need to be considered in highway constructions.

This paper identifies and compare the elements of green material and pavement technology used in existing green highway rating systems that can be implemented so that sustainable development in highway constructions can be achieved. Extraction of relevant information from literature review help to identify the importance level and appropriate elements in pavement material and technology that can be considered in green highway assessment tools.

2.0 PREVIOUS RESEARCHES ON PAVEMENT MATERIAL AND TECHNOLOGY ELEMENTS

Material and pavement technology elements should be seriously concerned by any party involves in highway development. A thorough review on sustainable elements in material and pavement technology may enhance an understanding of the green highway concept among the roadway practitioners.

Recycling existing pavement materials during rehabilitation and reconstruction of roads provides a more sustainable alternative compared to conventional methods such as full removal and replacement of the pavement materials [14]. Existing deteriorated asphalt surface can be pulverized and mixed with the underlying materials to form a new recycled base layer known as recycled pavement material (RPM). *In situ* recycling of roadway materials is actually a cost effective and environmentally friendly, resulting in reduced energy consumption, greenhouse gas emissions and waste material disposal [15, 16]. However, the asphalt binder in RPM and fines in the road surface gravel may adversely affect the strength, stiffness, and plastic deformation of recycled materials used as a base course [17-20]. The researchers are encouraged to do more researches on the performance and behaviour of recycled materials in pavement in order to ensure these recycle materials are acceptable and applicable.

One method to enhance the performance of these recycled roadway materials is chemical stabilization with binders like cement, asphalt emulsion, lime, cement kiln dust or fly ash. Besides, the utilization of waste industrial by product such as fly ash, steel slag, rubber, glass, etc. can reduce transportation, energy consumption and hazardous gas emission such as greenhouse gas CO_2. Moreover, it also minimizes the amount of waste material that will be dumped into landfill. The performance of plastic tar road conclusively proves that it is good for heavy traffic due to better binding, increased strength and better surface condition for a prolonged period of exposure to variation in climatic changes [21]. Indeed, the process would help to dispose waste plastics usefully and easily. The higher the recycling value, the more likely economically feasible can be obtained from the recycling or reuse activities [22].

Besides, the usage of Reclaimed Asphalt Pavement (RAP) and Recycled Concrete Material (RCM) in order to produce new pavement actually can minimize the dumping wastes of RAP and RCM in the landfill, reduce the consumption of virgin materials, and protecting the environment either using hot in-Place Recycling (HIPR) or Cold in-Place recycling (CIPR) methods. By practicing these recycling techniques, there is no excess material to haul and might reduce the fuel & transportation costs. The rubblized Portland Cement Concrete (PCC) layer has strength comparable to that of virgin PCC layer and has better performance under that structural condition [23].

The use of locally material on sites such as soil during cut and fill balance works has promoted reduce transportation cost to transport the soil, reduce energy consumption by the equipment and minimizes total cost of the project. Long life pavement eventually can reduce the maintenance cost and life cycle cost and may avoid frequent rehabilitation of pavement. It also can ensure a high level of safety to the road users [24].

Cool pavement is always related to the ‘albedo’, which can be defined as solar reflectance, where the higher albedo indicates high reflectance of sunlight energy by the pavement and vice versa. The tendency of high reflection of sunlight energy will reduce the ambient air temperature and can avoid the heat island effect. The use of warm mix asphalt (WMA) techniques allows for the reduction in required mixing energy and subsequently results in substantial energy cost savings [25]. It allows the production temperatures to be 10°C to 37.8°C lower than the conventional hot mix asphalt (HMA) production temperatures [26]. Besides, these lower temperatures actually can save burner fuel up to 35%.

One of the pavement technology elements is a permeable pavement where this type of pavement responsible to improve flow water control, especially during high rainfall intensity and quality of storm water runoff. Besides, they should meet storm water demands while providing a hard surface, which can be utilized in urban areas [27, 28]. Permeable pavements are alternatives to traditional impervious asphalt and concrete pavements. Interconnected void spaces in the pavement allow water to infiltrate into a subsurface storage zone during rainfall events. In areas underlain with highly permeable soils, the captured water infiltrates into the sub-soil. In areas containing soils of lower permeability, water can leave the pavement through an under drain system [29]. In comparison to conventional asphalts, permeable pavements provide more effective peak flow reductions (up to 42%) and longer discharging times. There is also a significant reduction of evaporation and surface water splashing too [30, 31]. In addition, concentrations of Total Suspended Solid (TSS), the total metals, and phosphorus were found to be significantly lower in runoff generated from the Permeable Friction Course (PFC) surface than in the runoff from the conventional hot mix asphalt surface based on previous research.

Another element in pavement technology is quiet pavement, which can generate noise reduction that produced from the interconnection between tire and pavement. Noise generated by the interaction between tire and pavement becomes a dominant source when the vehicle speed is at 35 km/h [32]. Therefore, many transportation agencies are investigating noise-reducing pavement to reduce road traffic noise. Experience reported from the United States, Europe, and Japan have shown that noise-reducing pavement can reduce a significant amount of traffic sound levels. These pavements include rubberized asphalt, open-graded asphalt, and stone mastic asphalt [33]. Level of noise is affected by the vehicle speed where the increasing of the vehicle speedcan generate the higher noise level. Therefore, by introducing quiet pavement in green highway, it will control and reduce the level of noise in our highway.

Soil bioengineering is a discipline dealing with hill slopes, riverbanks, and earth embankment stabilization, which in recent decades has gained worldwide popularity [34]. Its peculiarity consists in the technical use of vegetation, sometimes coupled with other materials. Owing to aesthetic and environment-friendly characteristics of vegetation, soil-bioengineering techniques are frequently adopted to achieve a low environmental impact of protective works within the fields of landscape architecture and environmental restoration.

In the bioengineering techniques element, it has focused on the slope protection and landscape development. In slope protection, it is suggested to protect the soil or embankment by using green techniques such as turfing, planting native vegetation, gabion wall, and hydro seeding. The utilization of soil biotechnical engineering treatment, which is the combination between the plant materials and structural elements, actually can contribute to the slope protection, stabilization and erosion control too.

WMA is one of technology that can be used in pavement development project in order to achieve sustainable green highway. In 1997, European countries started experimenting with WMA. The concept of the WMA is that substantial energy is spent to heat HMA to temperatures in excess of 150°C during production and compaction [35]. By reducing the heating temperature during production by 16 to 55°C lower than the typical HMA, WMA may provide significant energy savings to the asphalt industry too [36]. WMA have potential in the binder viscosity reduction as well as reducing the short-term ageing of the mixing during production [37, 38]. Therefore, several fields and experimental works have been conducted to determine and evaluate the performance of WMA mixtures [39-50]. Besides, WMA provides a reduction of 24% of the air pollution impact of HMA and reduce about 18% on fossil fuel consumption. WMA also may reduce by 15% of the environmental impacts of HMA as well.

Life cycle impacts are being used as a selection criterion for products and materials due to its importance. Therefore, a standard method which is widely used to evaluate comprehensively the environmental impacts of products can be defined as life cycle assessment (LCA). All the product life cycle that involves in environmental issue such as water, soil, waste, air, usage of raw materials, and nature exploitation are taken into consideration. In addition, this method may help to avoid the misallocation and reduce any possible environmental effects. LCA consists of complete life cycle of a product, from the beginning of productions, manufacturing, transportation and distribution, then reuse and recycling of materials, and finally disposal of materials. It is possible to learn the whole life cycle systems by using LCA technique [51].

Based on the previous researches that have been discussed, it is proved that all the elements in pavement material and technology bring more benefits towards economy, society, and the environment in order to achieve the green highway. Besides, these elements are also applicable to be selected and used in green highway rating systems.

3.0 HIGHWAY RATING SYSTEMS

The highway rating system can be defined as a tool that can be used as a sustainable guideline, which is specific in highway developments either in planning, design, construction, operation, or maintenance stages. By using the rating system, each performance of highway project can be measured and recognized due to the implementation of green practices such as the usage of low impact development tools, recycled materials, and local resources as long as it meet all the highway design, specifications, and safety requirements. Table 1 presents the percentage of each category in existing green highway rating systems, include material and pavement technology, environmental and water, design and construction, access and equity, and energy efficiency.

Based on Table 1, material and pavement technology yield the highest percentage among the other categories in Greenroads and GreenPave rating systems, which are 40% and 64% respectively. I-LAST, GreenLITES, Envision, and INVEST rating systems allocate the following percentage of material and pavement technology, respectively: 18%, 25%, 18% and 10%. From the table, it can be revealed that material and pavement technology actually one of the most important categories that would give high economic, environmental, and social impact to the highway development in order to achieve sustainable green highway.

Table 1 Percentage of category in green highway rating systems

Category	GreenLITES	Greenroads	I-LAST	GreenPave	Envision	INVEST
Material & Pavement Technology	25%	40%	18%	64%	18%	10%
Environmental & Water	8%	19%	37%	-	25%	2%
Design & Construction	30%	13%	20%	11%	36%	8%
Access & Equity (Social) / Others	2%	28%	18%	-	13%	73%
Energy Efficiency	35%	-	7%	25%	8%	7%

4.0 ELEMENTS OF MATERIAL AND PAVEMENT TECHNOLOGY

Table 2 shows the summary of existing green highway rating systems which include Greenroads, GreenLITES, I-LAST, GreenPave, Envision, and INVEST. The table is divided into two categories, which are material and pavement technology. Each category includes elements that stated in the existing rating systems and for any shortfall in the author's opinion.

Generally, elements for material and pavement technology in a Greenroads rating system are quite complete to achieve sustainable green highway, but it would be better if this rating system include the green materials or technologies for slope stabilization because it is a part of highway development too. The GreenPave rating system is encouraged to add the elements for slope stabilization and new green pavement technologies to ensure its rating system will be more practical and applicable in the future.

For GreenLITES, this rating system is only focusing on green materials used in highway construction, same goes to I-LAST rating system, which is more focusing on materials rather than pavement technology. Envision and INVEST rating tools are more focus on materials, especially in recycled, reuse, and locally usage of materials. This tool is suggested to include more elements of pavement technology due to its importance in achieving sustainable highway development.

Table 2 Green highway rating systems

Rating System	Year	Material Elements	Pavement Technology Elements	Comments / Shortfall
GreenLITES	2008	• Reuse of Materials • Recycled Content • Local Material • Bioengineering Techniques • Hazardous Material Minimization		• Only focus on green materials. • Should include green and new technology for pavement constructions.
Greenroads	2010	• Life Cycle Assessment (LCA) • Pavement Reuse • Earthwork Balance • Recycled Materials • Regional Materials • Energy Efficiency	• Long-Life Pavement • Permeable Pavement • WMA • Cool Pavement • Quiet Pavement • Pavement Performance Tracking	• Should cover up the green material and techniques for slope stabilization (erosion control).
I-LAST	2010	• Reuse of Top Soil • Balance Cut and Fill • Reuse Spoils within Project Corridor • Usage of Rubblization of Concrete Shoulder And Pavement • Usage of Recycled/Salvage Non Hazardous Material • Reuse Locally Produced By-products • Usage of Recycled Asphalt Pavement (RAP) • Environmentally Disposal of Surplus • Salvage/Moving of Buildings • Soil Stabilization • Locally Material	• Long Life Pavement and Rehabilitation Strategies	• More focus on green materials. • Should include more green and sustainable technology for pavements.
GreenPave	2010	• Recycled Content • Reuse of Pavement • Local Materials • Construction Quality	• Long Life Pavement • Permeable Pavement • Noise Mitigation • Cool Pavement	• More green techniques or technologies should be included for the development of pavement and also slope stabilization (erosion control).
Envision	2012	• Reuse of Material • Recycled Materials • Regional Material		• Encouraged to focus more on the material and pavement technology due to its importance in highway development.
INVEST	2012	• Recycled Materials • Regional Material • LCA • Pavement Reuse		• Need to include more elements of pavement material and technology to ensure this tool is applicable in highway construction.

Table 3 tabulates the elements of material and pavement technology in six existing green highway rating systems. Based on this table, "recycled materials" and "regional materials" yield the highest important elements which mean each of the six green highway rating systems are using these elements to achieve points in their highway projects. The least elements that have been considered by only one rating system are “bioengineering techniques” and “WMA”. Although these elements are only implemented by GreenLITES and Greenroads respectively, previous researchers have proven that these elements are applicable in achieving sustainable highway development as discussed in section 2.0.

Table 3 Elements of material and pavement technology in green highway rating systems

Element	GreenLITES	Greenroads	I-LAST	GreenPave	Envision	INVEST
Pavement Reuse	✓	✓	✓	✓		✓
Earthwork Balance	✓	✓	✓			
Recycled Materials	✓	✓	✓	✓	✓	✓
Reuse of Materials	✓		✓		✓	
Regional Materials	✓	✓	✓	✓	✓	✓
Long-Life Pavement		✓	✓	✓		
Permeable Pavement		✓		✓		
WMA		✓				
Cool Pavement		✓		✓		
Quiet Pavement		✓		✓		
Bioengineering Techniques	✓					
Hazardous Material Minimization	✓		✓			
LCA		✓				✓

The results are simplified in the ranking system as shown in Table 4. This table is divided into three columns which are the elements in the existing highway rating system, the total number of highway rating systems used the elements, and the ranking for the elements practiced. Accordingly, the most appropriate elements that have been considered and used in all six highway rating systems; Greenroads, I-LAST, GreenLITES, GreenPave, Envision, and INVEST are recycled materials and regional materials. These elements are in the first rank due to their usage in existing highway rating systems and benefit towards economic, environmental, and social aspects in order to achieve the sustainable green highway development.

Table 4 Ranking of elements in material and pavement technology based on green highway rating systems

Elements	Total Green Highway Rating Systems	Ranking
Recycled Materials	**6**	**1**
Regional Materials	**6**	**1**
Pavement Reuse	**5**	**2**
Earthwork Balance	**3**	**3**
Long-Life Pavement	**3**	**3**
Reuse of Materials	**3**	**3**
Permeable Pavement	**2**	**4**
Cool Pavement	**2**	**4**
Quiet Pavement	**2**	**4**
Hazardous Material Minimization	**2**	**4**
LCA	**2**	**4**
WMA	**1**	**5**
Bioengineering Techniques	**1**	**5**

■5.0 CONCLUSION

Pavement material and technology elements of sustainable highway during planning, design, construction, operation, and maintenance stages were derived from the six current green highway rating systems, including Greenroads, GreenLITES, I-LAST, GreenPave, Envision, and INVEST. The concepts of these elements used in highway development consist of two categories, which are pavement material resources and technology. Based on the result obtained, the most appropriate and recommended green elements to be practiced in green highway rating systems are recycled materials and regional materials. The application of elements in green materials and pavement technology actually can effectually decrease gas emissions and harmful substance, which has good economic, society, and environmental effects. Besides, the utilization of environment protection materials and pavement technology such as recycling techniques can reduce environment pollution to more extent. Therefore, all these elements are worth to apply or implement in any highway development projects. In addition, these elements might become a foundation to develop a complete green highway rating system in the future and can be implemented for sustainable practices in roadway constructions and designs in other countries that suits with the surroundings and weather.

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